

**IN THE UNITED STATES PATENT AND TRADEMARK OFFICE**

In re Application of:

Kalyan Muthukumar et al

Application No.: 10/809,716

Filed: March 24, 2004

For: Resource-Aware Scheduling for  
Compilers

Examiner: VU, Tuan A

Art Unit: 2193

**SUPPLEMENTAL AMENDMENT AND RESPONSE**

Mail Stop Amendment  
Commissioner for Patents  
P.O. Box 1450  
Alexandria, VA 22313-1450

Dear Sir:

In response to the Office Action mailed December 22, 2008, the amendment and response (mailed on April 8, 2009) to the Office Action mailed December 22, 2008, and the telephone discussion with the Examiner on June 19, 2009, Applicants respectfully request the Examiner to enter the following amendments and to consider the following remarks.

Amendments to the specification: NONE

Amendments to the claims: begin on page 2

Amendments to the drawings: NONE

Remarks/Arguments: begin on page 14

## AMENDMENTS TO THE CLAIMS

*Please amend the claims as follows:*

1. (Currently amended) A computer-implemented method of scheduling a plurality of instructions generated by a compiler based on an intermediate representation of source code, the method comprising:

for each of one or more of the plurality of instructions of one or more instruction types ready to be scheduled in a given cycle in a scheduling region, determining a new slack value based on a current maximum number of the instructions that can be scheduled in the given cycle for a target processor, wherein determining the new slack value comprises:

determining a minimum number of cycles needed to schedule each instruction in the scheduling region, taking resource height for each instruction into account, wherein the resource height is determined based on each resource availability for each instruction type to which each instruction belongs;

determining a dependence deadline based on a dependence height for each instruction and the minimum number of cycles, wherein the dependence height is determined based on a total height of a subgraph of a dependence graph of the scheduling region, and wherein the subgraph comprises one or more nodes to represent directly and indirectly dependent instructions of each instruction; and

determining a resource deadline based on the resource height and the minimum number of cycles;

selecting up to the current maximum number of instructions from those instructions ready to be scheduled in the given cycle, based on a priority order associated

with the new slack value; and  
scheduling the selected instructions.

2-3. (Canceled)

4. (Currently amended) The method of claim 3 1, wherein determining the new slack value comprises:

~~determining a dependence deadline based on the dependence height for each of the one or more instructions;~~

~~determining a resource deadline based on the resource constraints for each of the one or more instructions;~~

selecting as a deadline value that indicates a least number of cycles, between the resource deadline and the dependence deadline; and

determining the new slack value based on the selected deadline value.

5. (Previously presented) The method of claim 1, wherein the priority order comprises an ordering of the one or more instructions based on their new slack value, wherein the instructions with lowest slack value have highest priority.

6. (Previously presented) The method of claim 1, further comprising:

generating an entry in a ready list for each of the one or more instructions prior to determining the new slack value; and

removing the entry for the selected instructions from the ready list responsive to

scheduling the selected instructions.

7. (Previously presented) The method of claim 6, further comprising:

adding to an uncover list, any of the plurality of instructions not ready to be scheduled in the given cycle in the scheduling region that are uncovered by the scheduling of the selected instructions, wherein the instructions not ready to be scheduled are dependent on the selected instructions.

8. (Previously presented) The method of claim 6, wherein the given cycle is a given clock cycle, further comprising:

advancing a virtual clock to a subsequent clock cycle when there are no instructions in the ready list that can be scheduled in the given clock cycle; and

adding an entry to the ready list for any of the plurality of instructions not ready to be scheduled in the given cycle in the scheduling region that becomes ready in the subsequent clock cycle.

9. (Canceled)

10. (Currently amended) The method of claim 9 1, wherein determining the minimum number of cycles comprises:

determining a dependence length of the scheduling region;

determining a resource length of the scheduling region;

assigning the dependence length as the minimum number of cycles when the

dependence length is greater than the resource length; and

assigning the resource length as the minimum number of cycles when the resource length is greater than the dependence length.

11. (Currently amended) The method of claim 10, further comprising:

calculating the dependence length of the scheduling region based on the a total height of [[a]] the dependence graph of the scheduling region; and

calculating the resource length of the scheduling region based on the maximum number of cycles needed to schedule the one or more instructions in the scheduling region for the target processor.

12. (Canceled)

13. (Currently amended) An article comprising:

a computer readable medium having a plurality of machine accessible instructions stored thereon, which when executed by a computer, cause the computer to perform the following method:

for each of one or more instructions of one or more instruction types ready to be scheduled in a given cycle in a scheduling region, determining a new slack value based on a current maximum number of the instructions that can be scheduled in the given cycle for a target processor, wherein determining the new slack value comprises:

determining a minimum number of cycles needed to schedule each instruction in the scheduling region, taking resource height for each instruction

into account, wherein the resource height is determined based on each resource availability for each instruction type to which each instruction belongs;

determining a dependence deadline based on a dependence height for each instruction and the minimum number of cycles, wherein the dependence height is determined based on a total height of a subgraph of a dependence graph of the scheduling region, and wherein the subgraph comprises one or more nodes to represent directly and indirectly dependent instructions of each instruction; and

determining a resource deadline based on the resource height and the minimum number of cycles;

selecting up to the current maximum number of instructions from those instructions ready to be scheduled in the given cycle, based on a priority order associated with the new slack value; and

scheduling the selected instructions.

14-15. (Canceled)

16. (Currently amended) The medium of claim ~~45~~ 13, wherein determining the new slack value comprises:

~~determining a dependence deadline based on the dependence height for each of the one or more instructions;~~

~~determining a resource deadline based on the resource constraints for each of the one or more instructions;~~

selecting as a deadline value that indicates a least number of cycles, between the

resource deadline and the dependence deadline; and

determining the new slack value based on the selected deadline value.

17. (Previously presented) The medium of claim 13, wherein the priority order comprises an ordering of the one or more instructions based on their new slack value, wherein the instructions with lowest slack value have highest scheduling priority.

18. (Previously presented) The medium of claim 13, further comprising:  
generating an entry in a ready list for each of the one or more instructions prior to determining the new slack value; and

removing the entry for the selected instructions from the ready list responsive to scheduling the selected instructions.

19. (Previously presented) The medium of claim 18, further comprising:  
adding to an uncover list, any instructions not ready to be scheduled in the given cycle in the scheduling region that are uncovered by the scheduling of the selected instructions, wherein the instructions not ready to be scheduled are dependent on the selected instructions.

20. (Previously presented) The medium of claim 18, wherein the given cycle is a given clock cycle, further comprising:

advancing a virtual clock to a subsequent clock cycle when there are no instructions in the ready list that can be scheduled in the given clock cycle; and

adding an entry to the ready list for any instruction not ready to be scheduled in the given cycle in the scheduling region that becomes ready in the subsequent clock cycle.

21. (Canceled)

22. (Previously presented) The medium of claim 21, further wherein determining the minimum number of cycles comprises:

determining a dependence length of the scheduling region;

determining a resource length of the scheduling region;

assigning the dependence length as the minimum number of cycles when the dependence length is greater than the resource length; and

assigning the resource length as the minimum number of cycles when the resource length is greater than the dependence length.

23. (Currently amended) The medium of claim 22, further comprising:

calculating the dependence length of the scheduling region based on ~~the a~~ total height of ~~[[a]]~~ the dependence graph of the scheduling region; and

calculating the resource length of the scheduling region based on the maximum number of cycles needed to schedule the one or more instructions in the scheduling region for the target processor.

24. (Canceled)



25. (Currently amended) An apparatus for compiling a high-level programming language into an object code comprising:

a front end to receive a source code; and

a code generator, coupled to the front end, to:

receive the source code from the front end; and

compile the received source code into the object code,

wherein the code generator includes one or more resource-aware schedulers to:

for each of one or more instructions of one or more instruction types ready to be scheduled in a given cycle in a scheduling region, determine a new slack value based on a current maximum number of the instructions that can be scheduled in the given cycle for a target processor, wherein determining the new slack value is to:

determine a minimum number of cycles needed to schedule each instruction in the scheduling region, taking resource height for each instruction into account, wherein the resource height is determined based on each resource availability for each instruction type to which each instruction belongs;

determine a dependence deadline based on a dependence height for each instruction and the minimum number of cycles, wherein the dependence height is determined based on a total height of a subgraph of a dependence graph of the scheduling region, and wherein the subgraph comprises one or more nodes to represent directly and indirectly dependent instructions of each instruction; and

determine a resource deadline based on the resource height and the minimum number of cycles;

select up to the current maximum number of instructions from those instructions ready to be scheduled in the given cycle, based on a priority order associated with the new slack value; and

schedule the selected instructions.

26. (Currently amended) The apparatus of claim 25, wherein the one or more resource-aware schedulers are further to:

~~determine a first scheduling deadline for each of the one or more instructions in the scheduling region, taking dependence considerations into account;~~

~~determine a second scheduling deadline for each of the one or more instructions, taking resource constraints into account; and~~

~~select as a scheduling priority for each of the one or more instructions, between the first and second scheduling deadlines deadline value that indicates a least number of cycles, between the resource deadline and the dependence deadline; and~~

determine the new slack value based on the selected deadline value.

27. (Canceled)

28. (Previously presented) The apparatus of claim 26, wherein the priority order of the one or more resource-aware schedulers comprises an ordering of the one or more instructions based on their new slack value, wherein the instructions with lowest slack

value have highest priority.

29-30. (Canceled)

31. (Previously presented) The apparatus of claim 25, wherein the one or more resource-aware schedulers are to schedule the one or more instructions such that instructions of a particular instruction type are distributed evenly among two or more resources.

32. (Currently amended) A system comprising:  
a processor to execute each of one or more ready instructions; and  
a memory system, coupled to the processor, to store each of the one or more ready instructions;

wherein the instructions include a resource-aware scheduler to:

for each of one or more instructions of one or more instruction types ready to be scheduled in a given cycle in a scheduling region, determine a new slack value based on a current maximum number of the instructions that can be scheduled in the given cycle for a target processor, wherein determining the new slack value is to:

determine a minimum number of cycles needed to schedule each instruction in the scheduling region, taking resource height for each instruction into account, wherein the resource height is determined based on each resource availability for each instruction type to which each

instruction belongs;

determine a dependence deadline based on a dependence height for each instruction and the minimum number of cycles, wherein the dependence height is determined based on a total height of a subgraph of a dependence graph of the scheduling region, and wherein the subgraph comprises one or more nodes to represent directly and indirectly dependent instructions of each instruction; and  
determine a resource deadline based on the resource height and the minimum number of cycles;

select up to the current maximum number of instructions from those instructions ready to be scheduled in the given cycle, based on a priority order associated with the new slack value; and  
schedule the selected instructions.

33. (Previously presented) The system of claim 32, wherein the memory system comprises a Dynamic Random Access Memory (DRAM).

34. (Currently amended) The system of claim 32, wherein the resource-aware scheduler is further to:

determine a first scheduling deadline for each of the one or more ready instructions in the scheduling region, taking dependence considerations into account;

determine a second scheduling deadline for each of the one or more ready instructions, taking resource constraints into account; and

~~select as a scheduling priority for the instruction, between the first and second scheduling deadlines, deadline value that indicates a least number of cycles, between the resource deadline and the dependence deadline; and~~  
determine the new slack value based on the selected deadline value.

35. (Canceled)

36. (Previously presented) The system of claim 34, wherein the priority order of the resource-aware scheduler comprises an ordering of the one or more instructions based on their new slack value, wherein the instructions with lowest slack value have highest priority.

37-38. (Canceled)

## **REMARKS**

Claims 1, 3-11, 13, 15-23, 25-26, 28, 31-34 and 36 are currently pending. Claims 1, 4, 10-11, 13, 16, 23, 25-26, 32, 34 are amended. Claims 3, 9, 15, 21 are canceled. Applicants request reconsideration of claims 1, 4-8, 10-11, 13, 16-20, 22-23, 25-26, 28, 31-34 and 36 in view of the above amendments and the following remarks.

### **Telephone Discussion with the Examiner**

A telephone discussion was held with Examiner Tuan Vu on June 19, 2009. During the discussion, Applicants and the Examiner discussed about the potential allowance of claim 1 if claim 9 is incorporated into claim 1. The Examiner has suggested to change the term “resource constraint” to “resource height” if claim 9 is incorporated into claim 1 and also suggested to add the definition of the terms “dependence height” and “resource height” in the amended claim 1. Applicants have reviewed the suggestions from the Examiner and have made corresponding amendments in independent claims 1, 13, 25 and 32.

### **Conclusion**

Applicants respectfully submit that the rejections have been overcome by the amendment and remark, and that the claims as amended are now in condition for allowance. Accordingly, Applicants respectfully request the rejections be withdrawn and the claims as amended be allowed.

### **Invitation for a Telephone Interview**

The Examiner is requested to call the undersigned at (503) 439-8778 if there remains any issue with allowance of the case.

### **Request for an Extension of Time**

The Applicant respectfully petitions for extension of time to respond to the outstanding Office Action pursuant to 37 C.F.R. § 1.136(a) should one be needed. Please charge the fee under 37 C.F.R. § 1.17 for such extension to our Deposit Account No. 02-2666.

### **Charge our Deposit Account**

Please charge any shortage to our Deposit Account No. 02-2666.

Respectfully submitted,

BLAKELY, SOKOLOFF, TAYLOR & ZAFMAN LLP

Date: June 20, 2009

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